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THE EFFECTS OF REDUCED CONFIGURATIONS AT (LASA) ON DETECTION SIGNAL-TO-NOISE RATIOS

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The effects of varying the configuration of the Large Aperture Seismic Array (LASA) on the detection signal-to-noise ratio observed in the Seismic Data Analysis Center Detection Processor are discussed. It is shown that a configuration for the LASA of thirteen subarrays (A, B, C, and D rings) with 16 sensors per subarray produces an average loss of 0.2$\pm$0.3 db (one standard deviation of the mean) from the current configuration of seventeen subarrays (A, B, C, D, and E rings) using sixteen sensors per subarray. Reducing the

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THE EFFECTS OF REDUCED CONFIGURATIONS AT LASA ON DETECTION SIGNAL-TO-NOISE RATIOS

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ABSTRACT

The effects of varying the configuration of the Large Aperture Seismic Array (LASA) on the detection signal-to-noise ratio observed in the Seismic Data Analysis Center Detection Processor are discussed. It is shown that a configuration for the LASA of thirteen subarrays (A, B, C, and D rings) with 16 sensors per subarray produces an average loss of 0.2±0.3 db (one standard deviation of the mean) from the current configuration of seventeen subarrays (A, B, C, D, and E rings) using sixteen sensors per subarray. Reducing the number of subarrays to nine (A, B, and C rings) with only 7 elements per subarray produces an average loss of 3.5±0.3 db. These results are in general agreement with known results on variation of noise reduction and signal loss as a function of subarray and subarray sensor selection.

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INTRODUCTION

A series of off-line Detection Processor (DP) experiments were performed on data from the Large Aperture Seismic Array (LASA) in Montana to determine the effects that the number of subarrays and number of sensors per subarray have on the output of the computerized seismic analysis system at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The outputs of the system are the seismic events listed in a Daily Summary, the DP detections, etc. (See Dean et al., 1971, for a complete discussion of the SDAC/LASA system).

The functional flow of data from LASA through the SDAC/LASA system is: 1) data acquisition; 2) detection processing; 3) event processing; 4) experimental operations console (EOC) editing; and 5) publishing of the Daily Summary. The experiments discussed in this report concern themselves only with function 2), detection processing, and the resultant signal-to-noise ratios of the detected signals. The detection parameters used are those discussed by Chang (1974) using LASA Beam Set 133 in Partition I and LASA Beam Set 140 in Partition II. (Experiment 7, discussed below was an exception, using LBS 133 also in Partition II.)

Earlier studies of the effects of reducing the number of elements at LASA (Hartenberger, 1967; Hartenberger and Van Nostrand, 1970) have shown that the signal-to-noise ratio loss is less than 2db compared to that for the original 525 sensor array when the number of elements is reduced to 119 or 51 with minimum sensor spacing of 3km or 6km respectively. All of the data used in the earlier studies were prefiltered (0.4-3.0 Hz), were beamed to the known epicentral locations, and were corrected for travel-time anomalies (Chiburis, 1968). Also, the event set contained only earthquakes well above magnitude 4.7.

Such differences (between the present study and these earlier ones) as filter pass-band (0.9-1.4 Hz here) travel-time residuals, and subarray and array beam deployment may adversely affect an accurate comparison between them. The comparisons of relative S/N improvement between experiments in this paper should, however, be valid, since these parameters are held constant between experiments. Care must be taken, however, that non-detection of weak events by small subsets of the full LASA does not lead to biased estimates of the (S/N) loss. The experiments performed in this report simulate the on-line processing of a continuous data stream and include events near the detection threshold of the array (m_b = 3.7-4.0)

For reference, the configuration of LASA is shown in Figure 1, and a subarray configuration in Figure 2.

In order to vary any of the several DP parameters in the system for comparative analyses, an off-line DP set of programs, written by IBM under contracts F19628-67-C-0198 and F19628-68-C-0400, was used to simulate the on-line programs. The off-line DP results were then compared, detection by detection, and the effects of changing the array configuration were evaluated statistically.

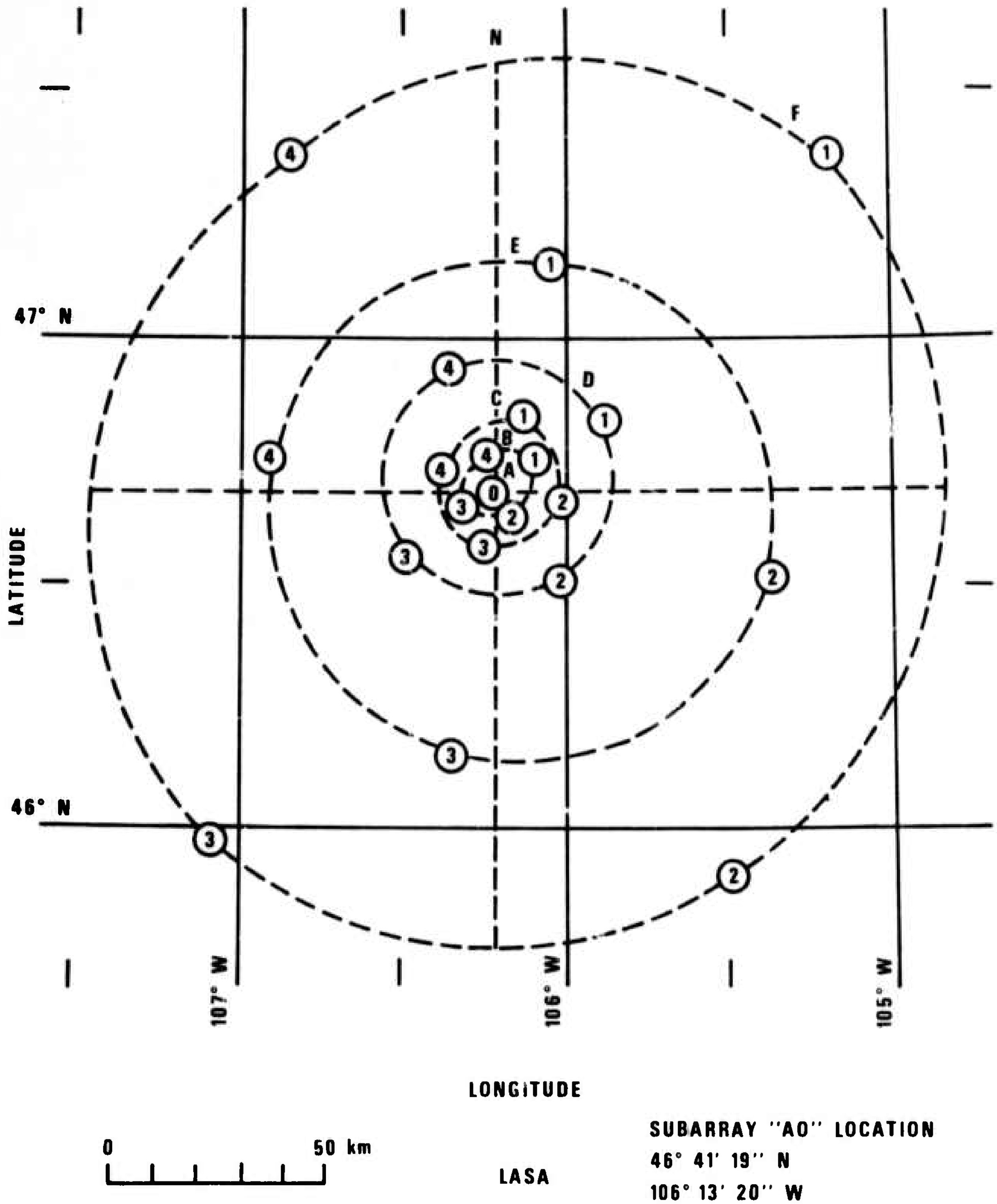
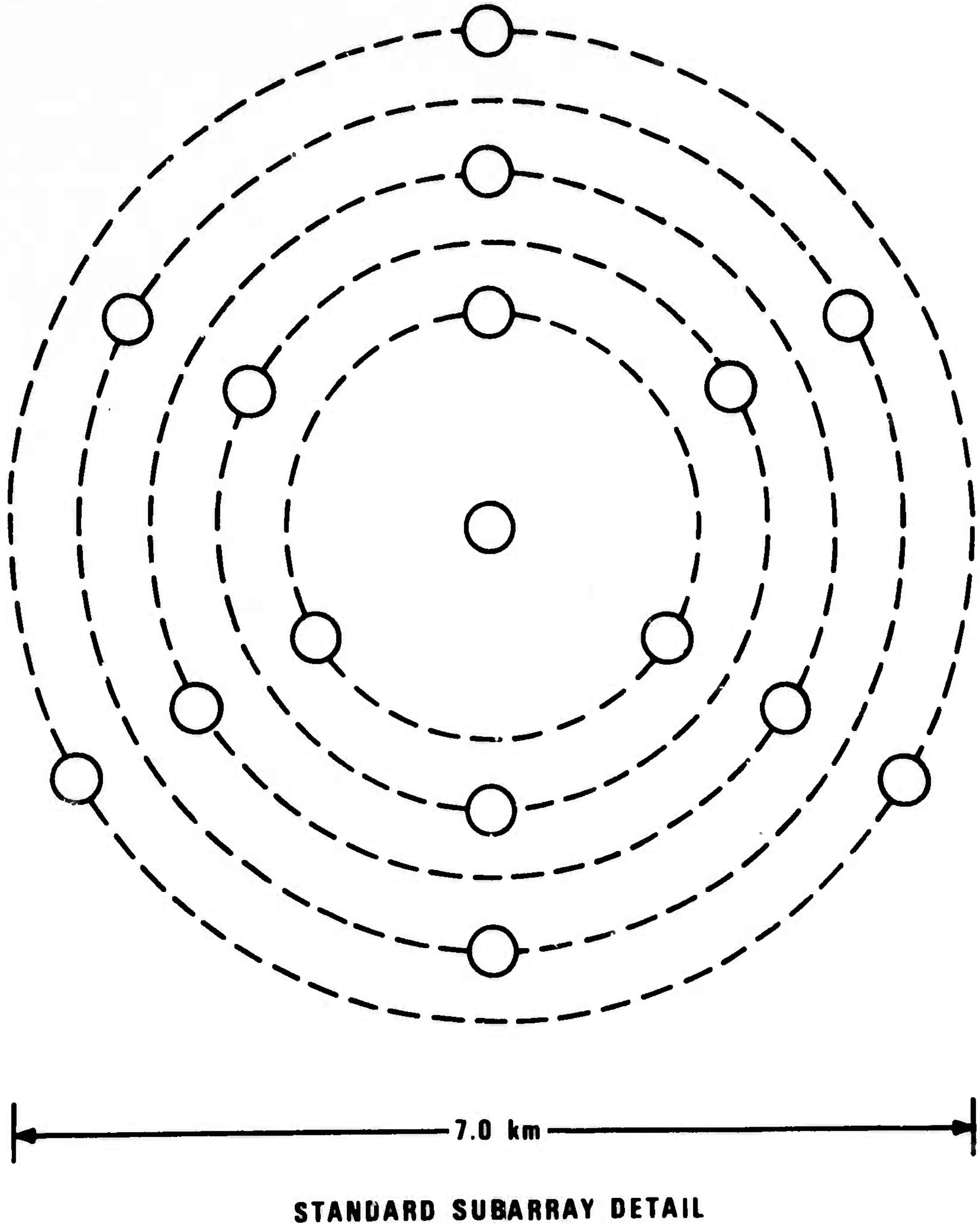


Figure 1. LASA configuration.



NOTE:
CENTER SEISMOMETER IS 500′ DEEP
OTHER SEISMOMETERS ARE 200′ DEEP

LASA

Figure 2. LASA subarray configuration.

PROCEDURE

The data selected for analysis are those 48 events appearing on the LASA bulletin for the time period May 22, 1930Z to 1972 May 23, 2040Z. A list of these events, taken from the LASA bulletin is given in the Appendix. This particular time period was selected because it had been analyzed earlier (Ahner, 1973) in the EP at a lower signal-to-noise threshold (10 db) than is normally used, and we felt that there would be no surprises in the data.

Of the 48 events in the Appendix, 7 are marked by an X and were not considered because their (S/N) ratio was less than 14db on the full array beam detections. This reduction helped minimize errors due to noise contamination of the signal. As we shall see, however, far fewer events than the remaining 41 were involved in the final calculations. The actual numbers range between 9 and 23. Many events were missed because of tape reading errors. These were by no means consistant from experiment to experiment; and as a result in several runs which should have been identical, different numbers of events were detected. Whenever a tape reading error was encountered, the computation of the long-term noise average (LTA) was disturbed. This also would introduce variations of detections from run to run. To minimize this effect; no events which occurred within 5 minutes of a tape reading error were considered. The LTA computations also had to be restarted each time one of the more than 30 tapes covering the time period came on line. In the runs with only a few sensors operational several events would of course simply be missed because of the lowered threshold.

Another reason for differing results between runs is that the LTA is updated only every third 0.6 second time-step. For some start times (after a faulty tape read for example) the LTA may be contaminated by the signal. Contamination of the LTA is in evidence in Figure 3 which shows the STA/LTA as a function of the STA for the 37 events detected by the full array in off-line Experiment 1 (to be discussed below). The event marked by X shows a severe contamination. Throughout this report events were removed from the plots and from calculation of mean S/N differences if the S/N difference with

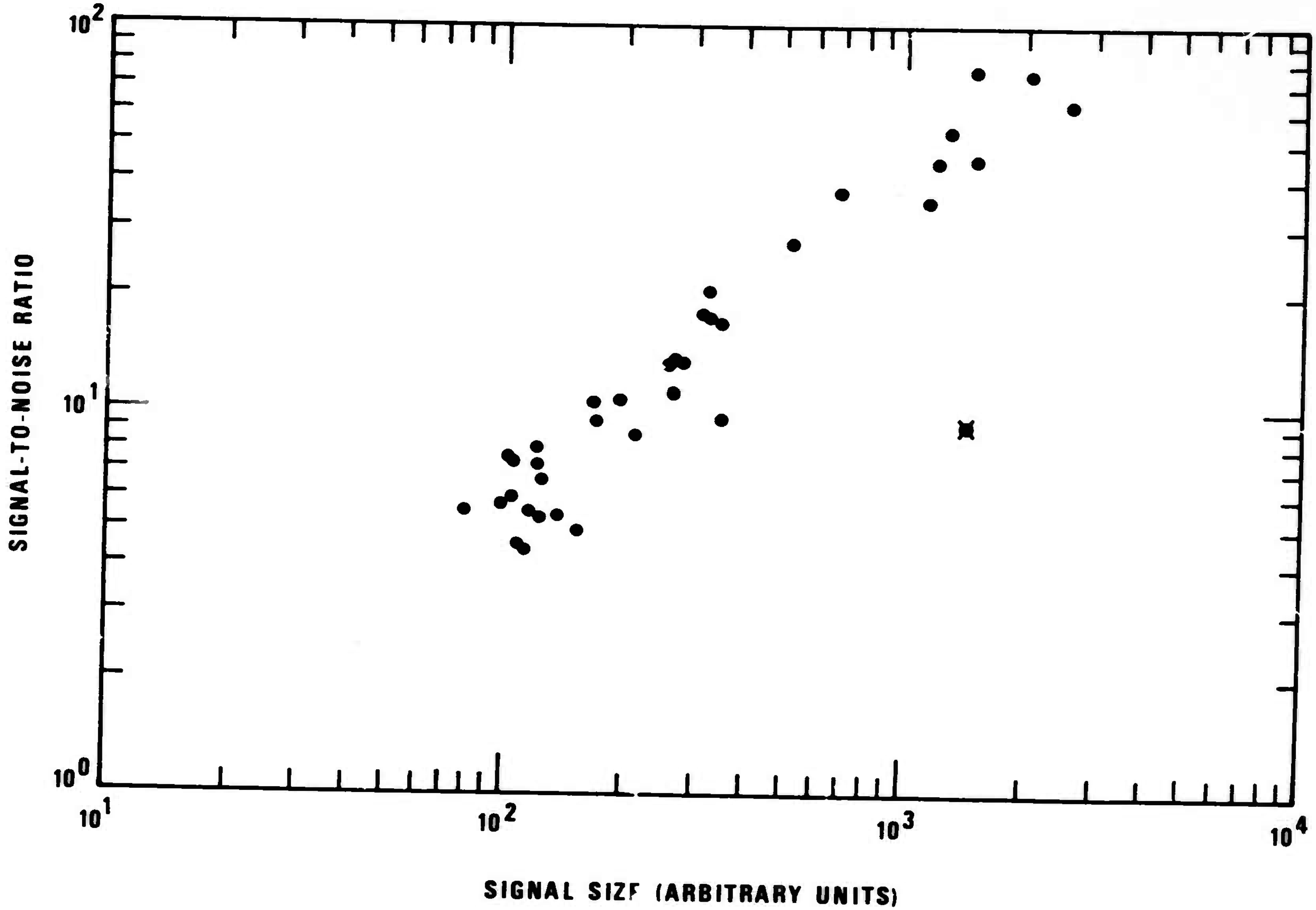


Figure 3. Signal-to-noise ratios as a function of signal strength.

respect to a standard run deviated from the mean by more than two standard deviations of an individual observation. This criterion lead to the loss of 2-4 events per experiment. No bias should result from this procedure since the error is equally likely to occur for either of two different experiments being compared.

It is noticable that the slope of the data points in Figure 3 is less than 1.0. This presumably arises because the LTA will be contaminated more if the signal under consideration is large.

The series of experiments selected to demonstrate the effect of subarray and sensor reduction is listed in Table I. In normal operations the on-line DP uses two different array configurations. The first, called Partition I, uses seventeen subarrays from the A, B, C, D, and E rings, and the second, Partition II, uses nine subarrays from the A, B, and C rings. Both partitions utilize sixteen sensors per subarray.

TABLE I

Array Configurations for Off-Line DP Experiments

Experiment	Number of Sensors/ Subarray	LBS 133 Number of Subarrays Partition I	Number of Sensors Partition I	LBS 140 Number of Subarrays Partition II	Number of Sensors Partition II
1	16	17(A,B,C,D, E)*	272	9(A,B,C)	144
2	10	17(A,B,C,D, E)	170	9(A,B,C)	90
3	7	17(A,B,C,D, E)	119	9(A,B,C)	63
4	16	13(A,B,C,D)	208	9(A,B,C)	144
5	13	13(A,B,C,D)	169	9(A,B,C)	117
6	10	13(A,B,C,D)	130	9(A,B,C)	90
7	7	13(A,B,C,D)	91	9(A,C,D)**	63

* Letters in parentheses refer to the subarray rings of the LASA.
** LBS 133 used here.

PRELIMINARY ANALYSIS

An initial observation of the effects of array size can be obtained, without resorting to the experiments listed in Table I, by using only the results of the on-line DP and comparing Partition I with Partition II. Figure 4a shows the on-line signal-to-noise ratio from Partition II (ordinate) compared to Partition I (abscissa). As can be seen, the (A, B, C) 144-element array of Partition II has, on the average, a signal-to-noise ratio 2.0 ± 0.2 (one standard deviation of the mean) db less than the (A-E) 272-element Partition I.

The array configuration in Partition I for Experiment 1 is identical to that of Partition I of the on-line array. In Figure 4b we compare off-line to on-line results. We expect to see little difference if the off-line DP package is performing correctly. We observe no difference, and in fact the average loss in Experiment 1 was 2.0db. Hence, it is assumed that the off-line DP programs are adequate for simulating the on-line DP programs. All subsequent reduced array experiments are compared to the Partition I off-line simulation in Experiment 1.

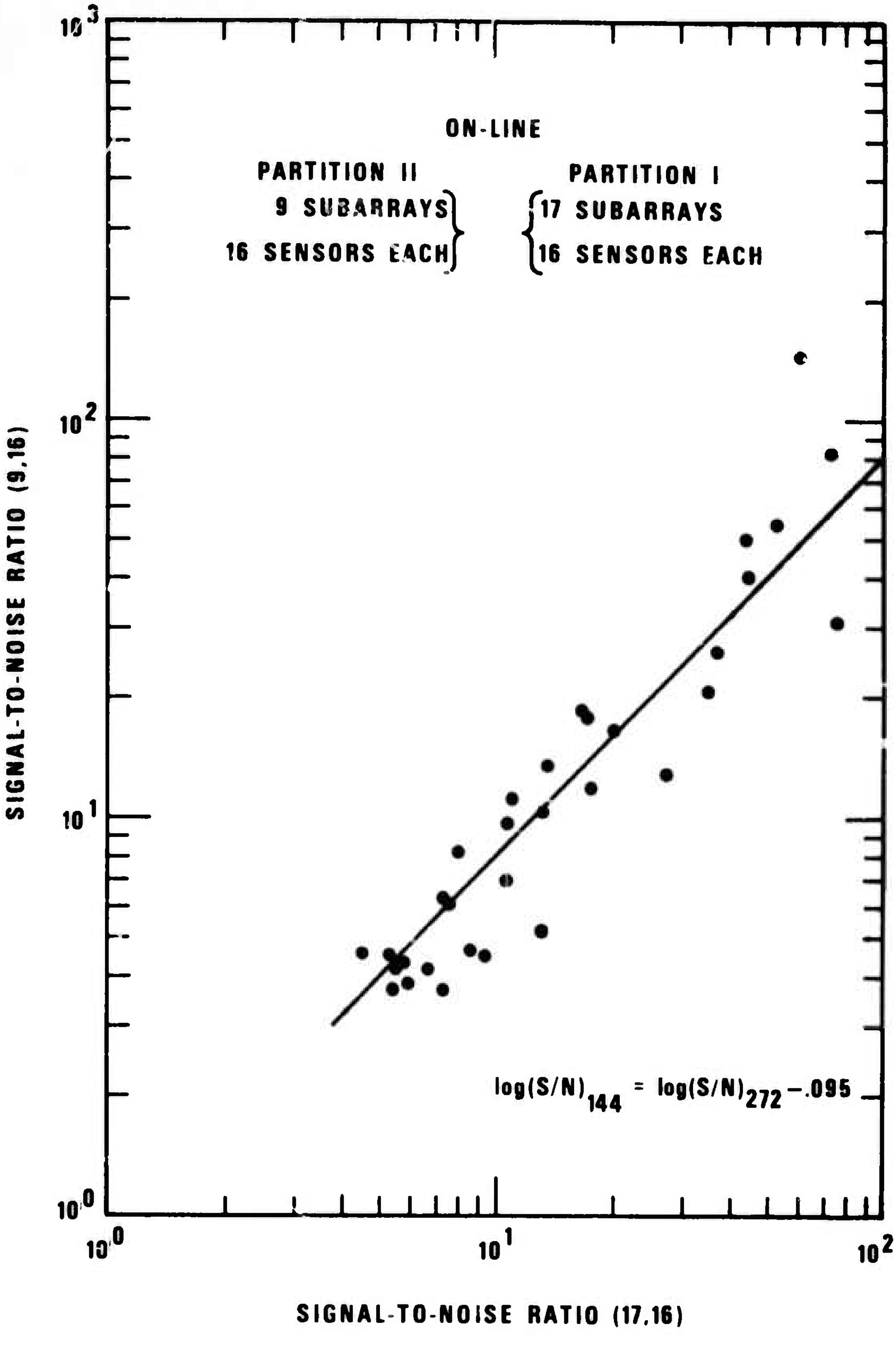


Figure 4a. Comparison of the two detection beamsets in the on-line system (Partition II vs Partition I). Intercept of the line with unit slope is determined by the average difference in log (S/N) between partitions.

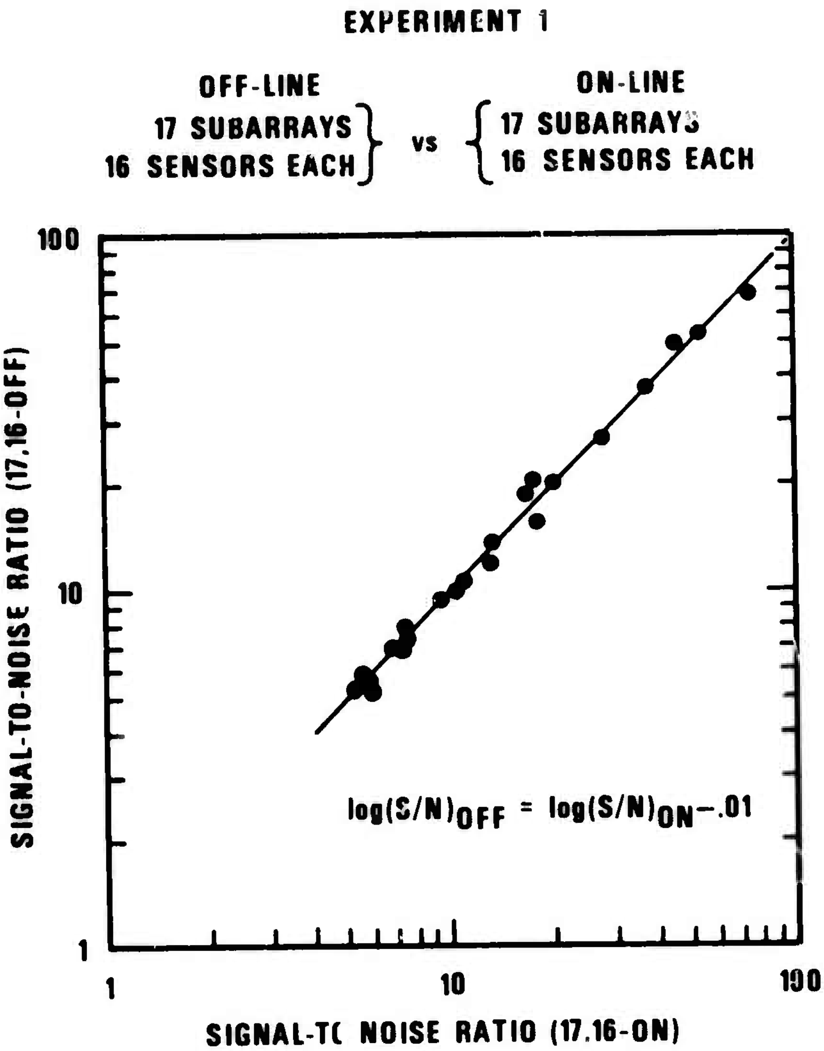


Figure 4b. Comparison of on-line and off-line systems.

RESULTS OF EXPERIMENTS

The array configuration for Experiment 2 retains seventeen subarrays for Partition I and nine subarrays for Partition II, but the number of sensors per subarray is reduced from sixteen to ten by dropping the inner two rings of sensors from each subarray (see Figure 2). The results are shown in Figure 5. The signal-to-noise ratio loss relative to Experiment 1, due to the sensor reduction, averages 0.8db for Partition I and 2.3db for Partition II.

The configurations for Experiment 3 are seventeen and nine subarrays with seven sensors per subarray, obtained by dropping the inner three rings in each subarray. The results are shown in Figure 6. The relative loss for Partition I averages 1.8db, and for Partition II, 3.5db.

For Experiment 4, the array aperture is reduced to one half by dropping the E-ring subarrays (leaving a total of thirteen subarrays), but the number of sensors per subarray is returned to sixteen. The results are shown in Figure 7 where the Partition I loss averages only 0.2db and the Partition II loss averages 2.6db. The significant result of Experiment 4 is that the signal-to-noise ratio losses are so small when the E-ring is dropped from the array. The reason for this result is that any loss due to a higher noise background with the smaller number of sensors is off-set by better signal correlation between subarrays which are closer together (Hartenberger and Van Nostrand, 1972).

The configuration for Experiment 5 is similar to Experiment 4, except that the number of sensors per subarray is reduced from sixteen to thirteen (inner ring dropped from each subarray). The results, shown in Figure 8, indicate a Partition I average loss of 0.4db and a Partition II average loss of 2.5db.

Reducing the number of sensors per subarray to ten and using thirteen subarrays (Experiment 6), yields the results shown in Figure 9. The Partition I loss averages 0.8db and the Partition II loss averages 3.1db. Experiment 7, with the lowest total number of sensors in the entire set of experiments, has a configuration of thirteen subarrays (Partition I) and

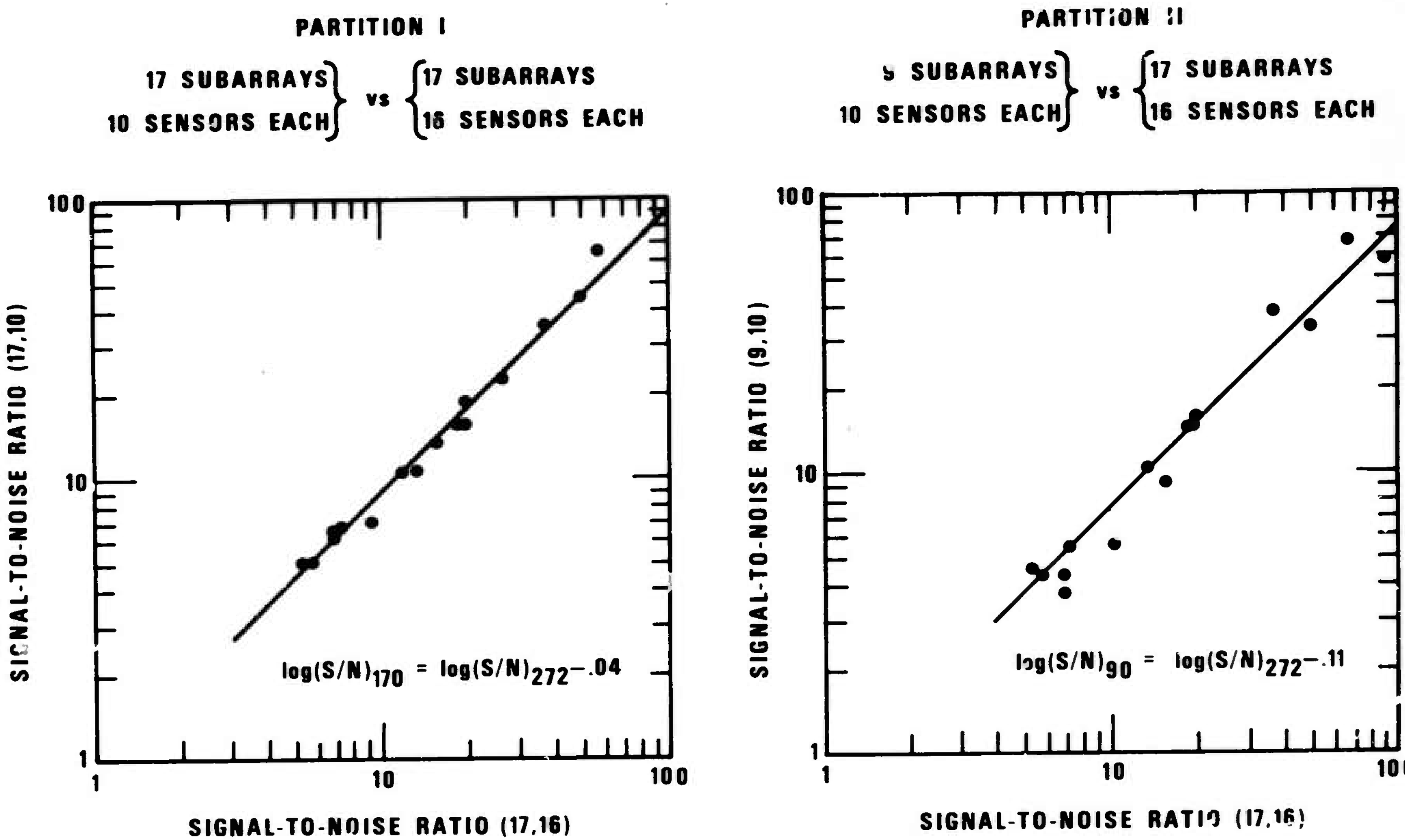


Figure 5. Experiment 2 results.

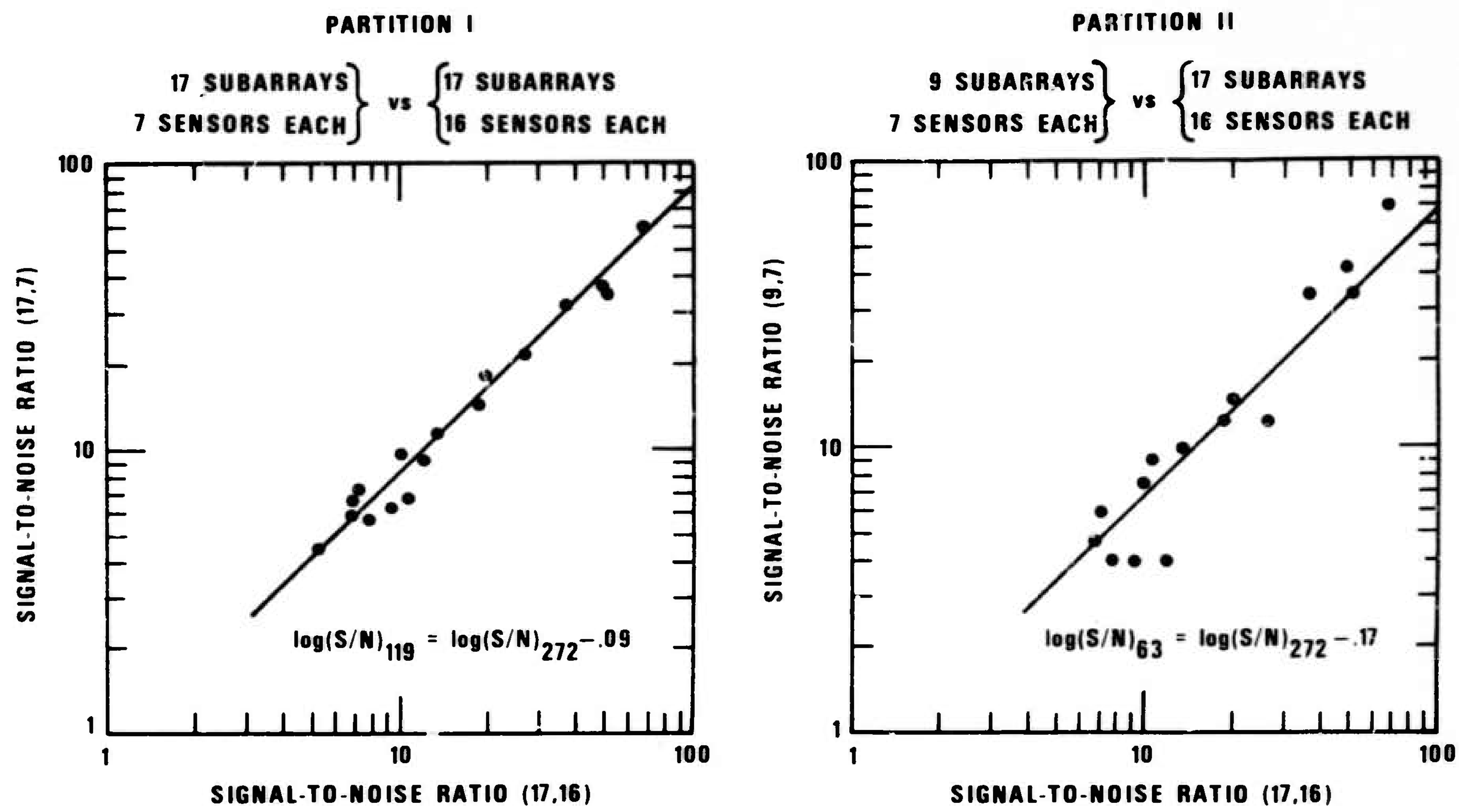


Figure 6. Experiment 3 results.

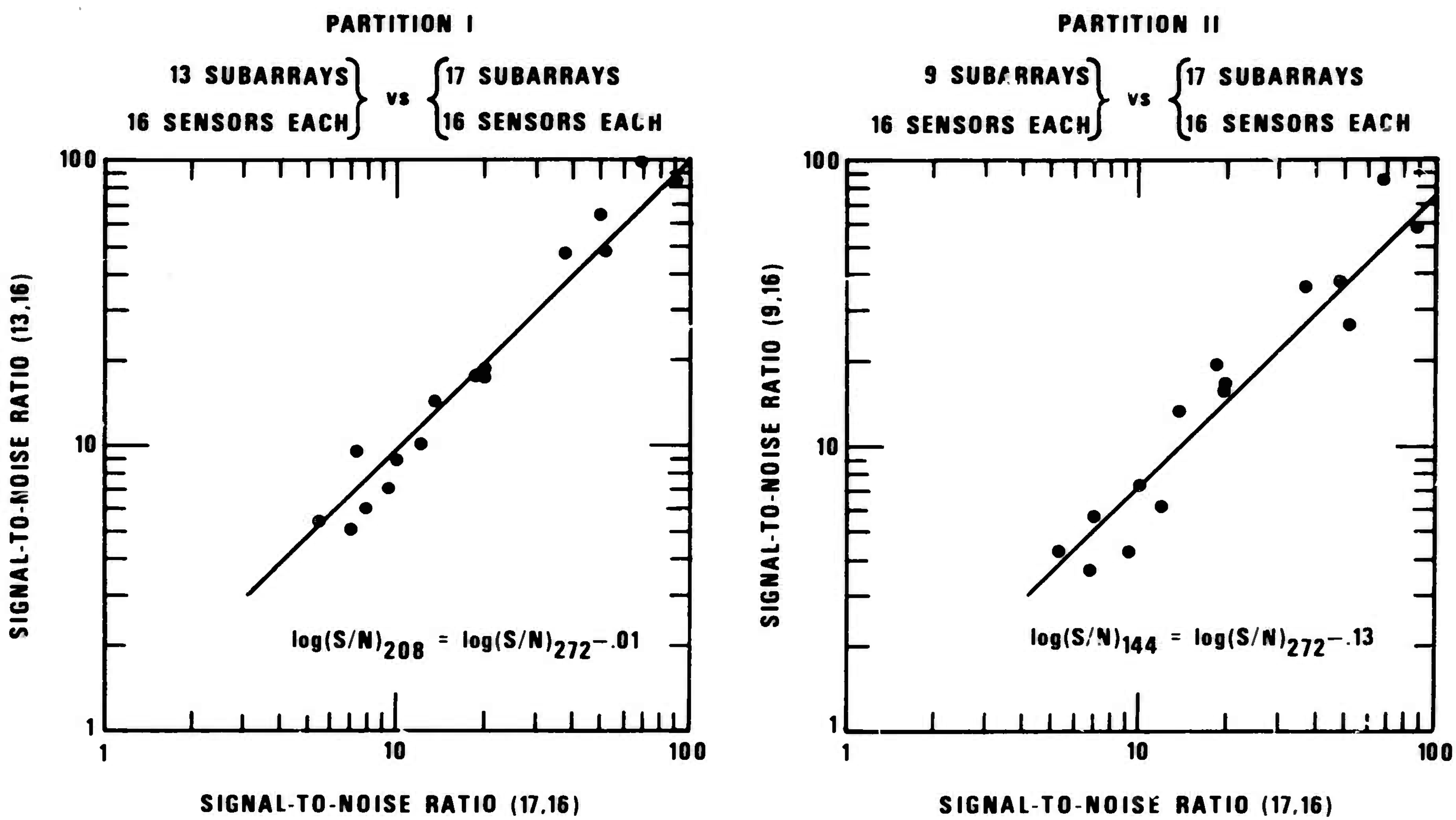


Figure 7. Experiment 4 results.

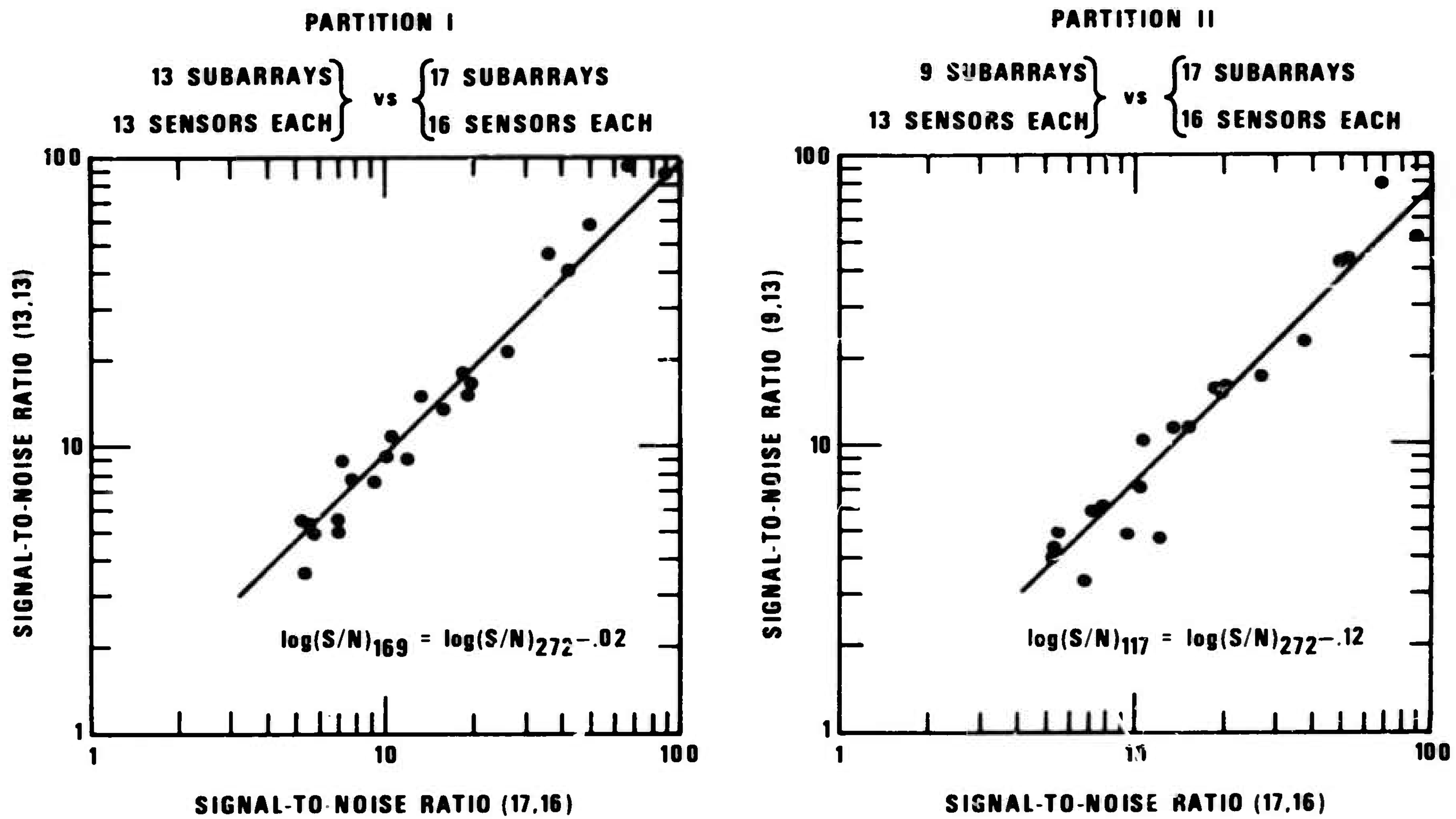


Figure 8. Experiment 5 results.

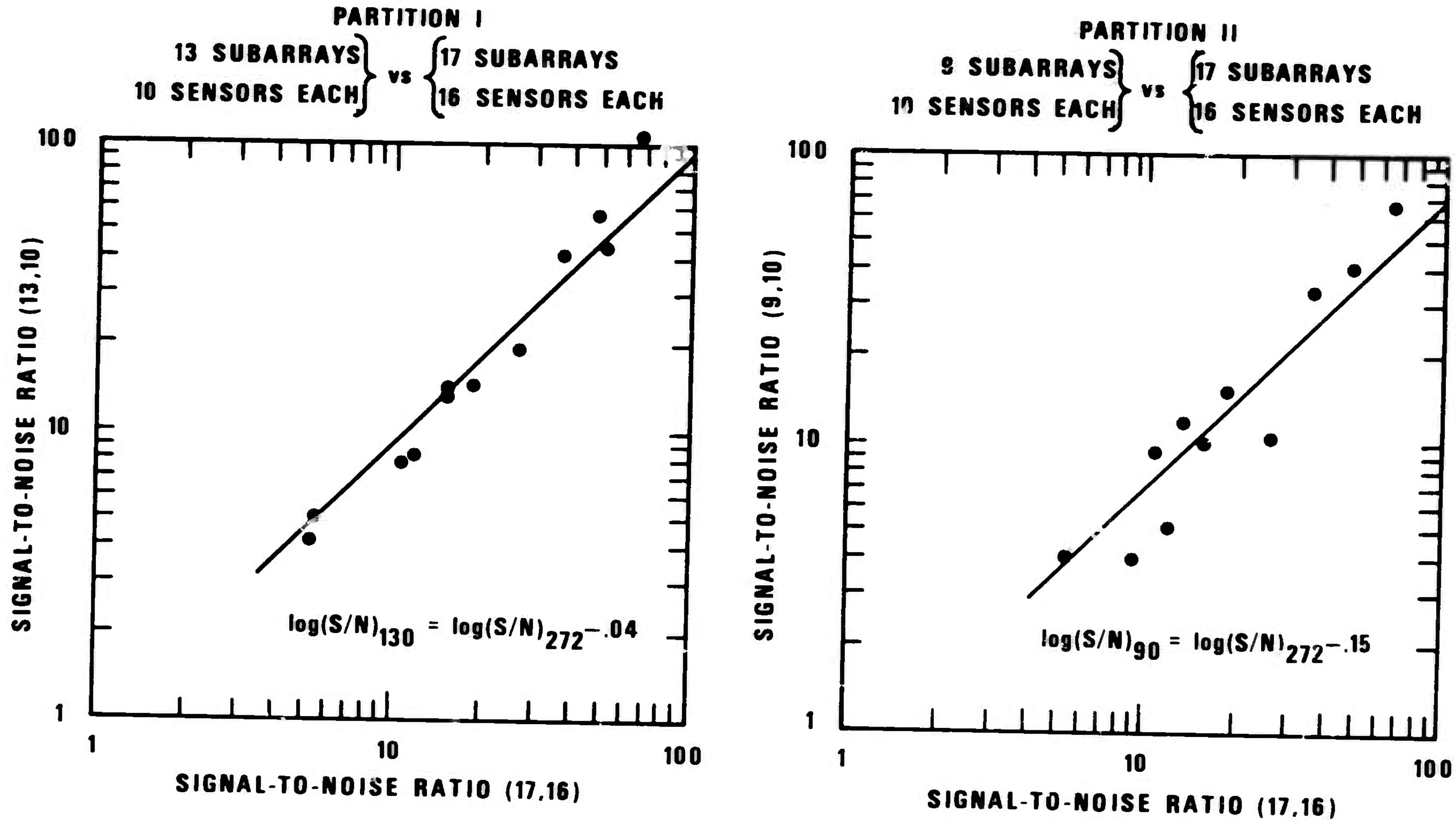


Figure 9. Experiment 6 results.

nine subarrays (Partition II), both with seven sensors per subarray. However, the nine subarrays in Partition II for Experiment 7 are composed of the A, C, and D subarrays, instead of the usual A, B, and C subarrays. The reason for this change is to note the contributions to the signal-to-noise ratio made by the B-ring subarrays which are close to the A- and C-ring subarrays (see Figure 1). Since LBS 140 was designed only for the low aperture ABC ring LASA, LBS 133 was inserted in Partition II for this Experiment. The results, shown in Figure 10, indicate a Partition I average loss of 1.8db and a Partition II average loss of 11.1db. This latter figure is far out of line with what is expected by comparison with Partition II of Experiment 3 which had a loss of 3.5db for the A, B, and C rings. We initially thought that the trouble might be that the direct sum of the individual traces was so small that truncation error in the computer was the cause of the problem. Therefore we repeated the run with all of the raw data scaled up by a factor of 4. While 15 events were detected in this case, as compared to 9 in the previous one; the events in common had an average mean log S/N value within .05 units of each other. Thus there appeared to be no errors of computation. Close examination of the detection beam numbers for Partition II showed that approximately 80% of the detections were not on the same beam number as the detections in Partition I of Experiment 1; whereas for Experiment 3, 80% of the detections were on the same beam number. This fact suggests a large number of side-lobe detections. This would be consistant with the fact that elimination of the B ring subarrays will sharpen the main lobe of the full array at the expense of greatly increasing the side lobe amplitudes. Detections on the side lobes will, of course, have low signal-to-noise ratios. Averaging over all detected events in both repetitions of Experiment 7 we obtain a loss of 6.2db. However, because of the side lobe problem discussed above, these results should not be compared to theoretical predictions. This problem should, however, be kept in mind in the design of new arrays; the lesson is that a compact array design will make the task of automatic detection simpler.

Examination of Figures 5-11 reveals the effect of signal contaminated noise. At high S/N levels the points tend to lie above the line. Since the noise level is lower for the standard (Partition I, Experiment 1), it

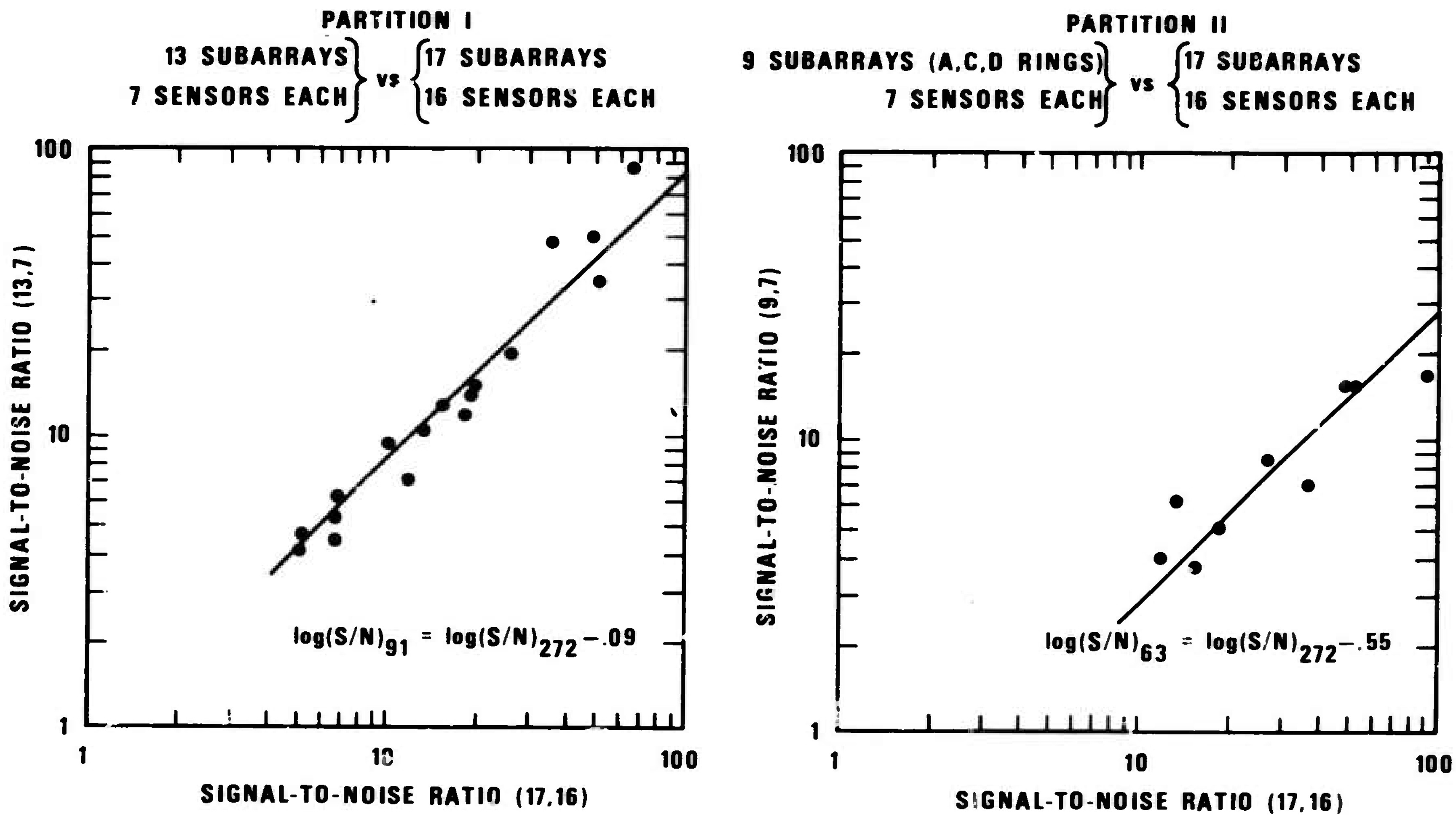


Figure 10. Experiment 7 results.

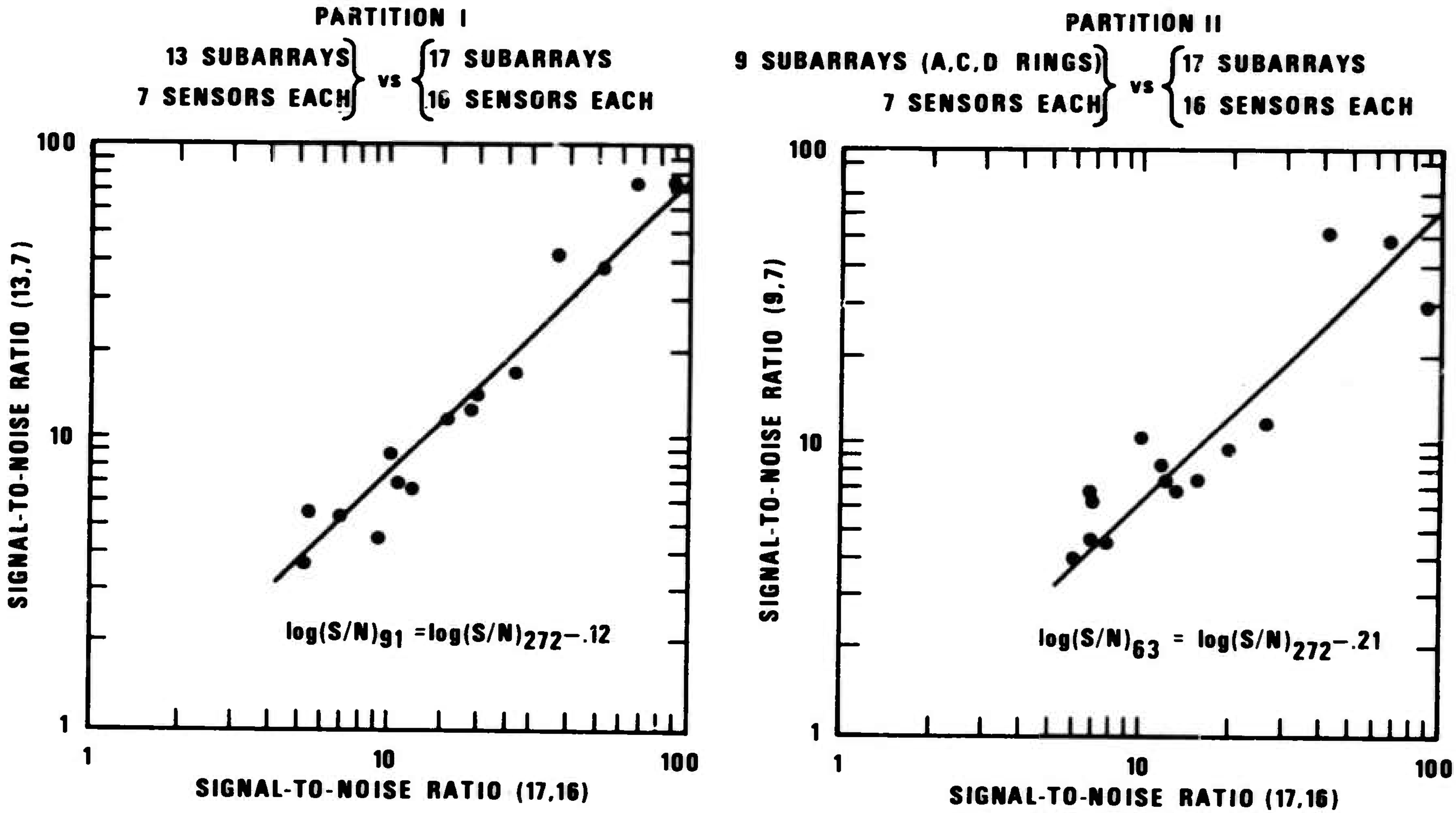


Figure 11. Repeat of Experiment 7 with the raw data scaled upward in amplitude by a factor of four within the Detection Processor.

experiences a greater percentage increase due to signal contamination; and this results in a greater reduction of S/N. Quantitatively the effect is small; omitting these points would increase the loss by ~0.3db in the most severe case.

The results of the seven experiments are summarized in Table II. We also give the predicted noise loss in the pass-band 0.8-2.0 Hz by using the estimation techniques of Blandford and Clark (1971) at the subarray level, and assuming $\sqrt{N}$ noise reduction between subarrays. The difference between these predictions and the observed loss may be called the apparent signal loss. (Of course we expect some error here since the actual noise and signal pass-band is 0.9-1.4 Hz. Examination of Figure 6 in Blandford and Clark, together with the realization that the noise loss is controlled by the low-frequency end of the spectrum and that only relative loss is of concern in this analysis leads to the conclusion that the error is on the order of 0.2db.)

A rough confidence interval on the observed loss values may be obtained by noting that the average standard deviation of a signal loss estimate from the mean of an experiment, averaged over Experiments 1-6, is 1.2db. Since the average number of observations per experiment is 15, the average standard deviation of the mean would be about 0.3db; and a 95% confidence interval would be about 0.6db.

Comparing Row 1 to Row 4 in Table II we see that the apparent signal loss from dropping the E ring is -1.0db. That is, there is less signal loss: as would be expected. This result is in agreement with the reduction of signal loss of 0.9db for a Ryuku event in the pass-band 0.7-2.0 Hz found for dropping the E ring by Hartenberger and Van Nostrand (1972).

As the number of sensors per subarray decreases however (rows 2 and 3 compared to 1; rows 5, 6, and 7 compared to 4) the signal loss becomes greater. This is due, we believe, to the fact that the travel-time residuals are set for the center sensor of the array. As the number of sensors per array is reduced, the average contribution of sensors near the center element is reduced; thus increasing the signal loss. For 9 subarrays this pattern is not so apparent: we see only that the loss in row 13 for 7 sensors per subarray is less negative than it is for 10, 13, or 16 elements per subarray.

TABLE II

Summary of Results

Row No.	No. Of Subarrays	No. Of Sensors/Subarray	No. Of Events	Observed Loss, db	Expected Noise Loss 0.8-2.0 Hz	Residual (Apparent relative Signal Loss)	Experiment Number
1	17	16	37			0	1(reference)
2	17	10	16	0.8	.5	.3	2
3	17	7	17	1.8	.8	1.0	3
4	13	16	16	0.2	1.2	-1.0	4
5	13	13	23	0.4	1.4	-1.0	5
6	13	10	12	0.8	1.7	- .9	6 LBS 133
7	13	7	15	2.4	2.0	.4	7
8	9	16	22	2.3 {2.0	2.8	- .5	1
9	9	16	15	2.6	2.8		4 LBS 140
10	9	13	21	2.5	3.0	- .5	5
11	9	10	15	2.7 {2.3	3.3	- .6	2
12	9	10	11	3.1	3.3		6
13	9	7	15	3.5	3.6	- .1	3
14	9(A,C,D rings)	7	9+15	6.2*	3.6	2.6*	7

* Average of two runs; the large apparent signal loss is believed due to S/N measured on side lobe detections resulting from the large side lobes resulting from the absence of the B ring.

The above discussion suggests that the observed loss figures have their roots in geophysically real effects, and that they can, therefore, be trusted as the best available estimates of the signal-to-noise ratio loss we may expect from such array modifications.

In Figure 12 we have plotted the observed loss as a function of number of sensors per subarray for different numbers of subarrays. We see that dropping the E ring results in a S/N loss of less than 0.2db; while dropping the D and E ring and reducing the number of sensors from 16 to 7 results in a loss of 3.5db. We have seen that the standard deviation of these estimates is approximately 0.3db.

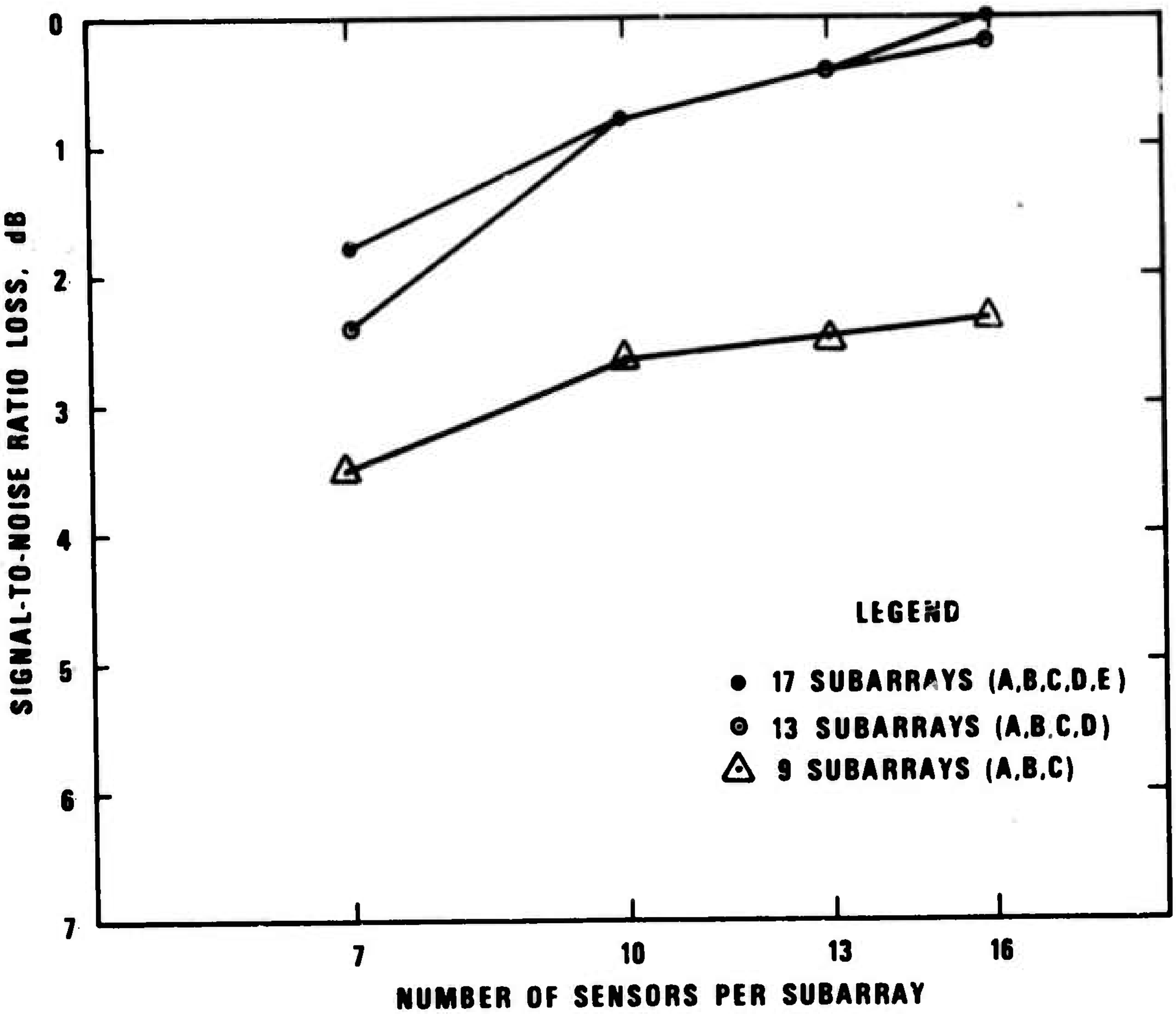


Figure 12. Summary of results.

CONCLUSIONS

The results obtained from the present study, in which several experiments were performed on LASA data with reduced array configurations, lead to the following conclusions:

1. The detection signal-to-noise ratio for a 16 element subarray D-ring size LASA is within 0.2±0.3db of that for an E-ring sized LASA.

2. Further reducing the array to an aperture of the C-ring produces losses of 2.3±0.3db.

3. Eliminating, within a subarray, the six sensors nearest the center produces less than one db of loss in the detection signal-to-noise ratio.

The foregoing conclusions are based on the assumption that each subarray is beamed before the entire array is beamed. If infinite-velocity subarray beams are formed, the results can be expected to differ from those in this report. The effects of infinite-velocity subarray beams, and number of sensors per subarray, are currently under investigation.

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YR MO DAY	ORIGIN TIME	LATITUDE	LONGITUDE	DEPTH	MB	GRN	GEOGRAPHIC REGION NAME	SRN
72 May 22	18 19 52.0	33.300N	142.000E	040G	3.90	229	Off East Coast of Honshu	19
72 May 22	19 25 51.0	33.800N	141.500E	033C	3.40	229	Off East Coast of Honshu	19
72 May 22	20 45 45.0	16.200S	174.600W	033	6.70	173	Tonga Islands	12
72 May 22*	20 54 06.0	36.900N	38.300E	033C	4.00	374	Jordan - Syria Region	30
72 May 22	21 04 38.0	24.500N	110.400W	033C	4.30	048	Baja, California	04
72 May 22*	21 03 29.0	45.500N	12.600E	033C	3.90	545	Northern Italy	36
72 May 22	21 56 19.0	25.600N	109.200W	033C	3.40	049	Gulf of California	04
72 May 22	22 35 05.0	18.500S	174.900W	033C	4.10	173	Tonga Islands	12
72 May 22	23 37 22.0	29.500N	139.500E	035G	3.80	211	South of Honshu, Japan	18
72 May 23	00 00 57.0	4.800S	76.200W	033C	3.70	111	Northern Peru	08
72 May 23	00 23 45.0	15.200S	76.100W	020G	3.80	114	Off Coast of Peru	08
72 May 23	00 38 10.0	18.100N	93.600W	075G	4.60	527	Gulf of Campeche	34
72 May 23	00 38 38.0	17.600N	94.000W	040G	4.70	061	Chiapas, Mexico	05
72 May 23	02 05 03.0	54.400N	163.900W	033C	3.60	010	Unimak Island Region	01
72 May 23*	02 24 41.0	15.900S	172.900W	033C	3.40	169	Samoa Islands Region	12
72 May 23	02 36 42.0	24.600N	75.200W	033C	4.90	515	Bahama Islands	34
72 May 23	02 41 56.0	33.200N	140.000E	033C	3.40	211	South of Honshu, Japan	18
72 May 23	03 14 35.0	41.600N	23.500E	033C	4.70	363	Greece-Bulgaria Border R	30
72 May 23	03 36 25.0	31.200N	131.600E	035G	3.60	235	Kyushu, Japan	20
72 May 23*	04 19 20.0	51.300N	177.700W	033C	3.00	007	Andreanof Islands, Aleut	01
72 May 23	06 37 42.0	2.100N	154.000E	033C	4.40	614	Caroline Islands Region	39
72 May 23	07 31 01.0	24.800S	173.000W	033C	3.80	175	South of Tonga Islands	12
72 May 23	08 06 13.0	9.800N	56.100W	033C	3.40	402	North Atlantic Ocean	32
72 May 23*	08 55 03.0	4.200N	76.200W	033C	3.10	103	Colombia	08
72 May 23	09 44 15.0	39.900N	18.000E	033C	3.60	390	Southern Italy	31
72 May 23	09 57 04.0	38.400N	34.100W	033C	4.30	404	Azores Islands Region	32
72 May 23	10 05 13.0	39.000N	35.300W	033C	4.80	402	North Atlantic Ocean	32
72 May 23	10 08 39.0	38.600N	34.700W	033C	4.00	404	Azores Islands Region	32
72 May 23	10 30 41.0	53.500N	68.600E	033C	3.50	713	Central Kazakh SSR	48
72 May 23	10 49 53.0	39.200N	36.300W	033C	3.50	402	North Atlantic Ocean	32
72 May 23	11 04 31.0	39.100N	15.300E	033C	4.10	390	Southern Italy	31
72 May 23*	11 49 48.0	50.100N	177.900W	033C	3.20	007	Andreanof Islands, Aleut	01
72 May 23	11 51 47.0	32.700N	140.600E	033C	4.50	211	South of Honshu, Japan	18
72 May 23	11 58 06.0	34.000N	141.000E	065G	3.60	229	Off East Coast of Honshu	19
72 May 23	12 15 15.0	47.400N	149.900E	033C	3.70	220	Northwest of Kurile Islands	19
72 May 23	12 54 59.0	33.100N	142.100E	033C	3.40	229	Off East Coast of Honshu	19
72 May 23	14 14 21.0	52.800N	171.900W	033C	3.30	009	Fox Islands, Aleutian Is.	01

YR MO DAY	ORIGIN TIME	LATITUDE	LONGITUDE	DEPTH	MB	GRN	GEOGRAPHIC REGION NAME	SRN
72 May 23	16 05 27.0	7.200N	71.300W	033C	3.50	101	Venezuela	07
72 May 23*	16 27 45.0	18.100S	71.100W	033C	3.40	121	Off Coast of Northern Ch	08
72 May 23	16 42 37.0	22.700S	69.200W	110G	4.80	123	Northern Chile	08
72 May 23	17 21 52.0	33.400N	142.600E	090G	4.20	229	Off East Coast of Honshu	19
72 May 23	18 03 33.0	33.500N	142.500E	035G	5.00	229	Off East Coast of Honshu	19
72 May 23	18 18 38.0	59.700N	145.800W	033C	3.80	015	Gulf of Alaska	01
72 May 23	18 17 04.0	35.700N	70.600E	033C	4.90	718	Hindu Kush Region	48
72 May 23	19 16 19.0	32.400N	142.700E	035G	4.30	211	South of Honshu, Japan	18
72 May 23	19 29 57.0	33.300N	141.300E	033C	3.80	229	Off East Coast of Honshu	19
72 May 23	19 37 57.0	53.500N	157.400E	033C	3.40	217	Kamchatka	19
72 May 23	20 28 23.0	53.400N	160.700E	033C	3.50	218	Near East Coast Kamchatk	19

* <14 dB